Recommended Practice for Preproduction Qualification for Steel Plates for Offshore Structures

API RECOMMENDED PRACTICE 2Z
FOURTH EDITION, SEPTEMBER 2005

REAFFIRMED, OCTOBER 2010

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AMERICAN PETROLEUM INSTITUTE

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Upstream Segment

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FOREWORD

This Recommended Practice is under jurisdiction of the API Subcommittee on Standardization of Offshore Structures.

The purpose of this recommended practice is to provide recommendations for the pre-production qualification of steelmaking procedures for steel plates for use in welded offshore structures.

This standard shall become effective on the date printed on the cover but may be used voluntarily from the date of distribution.

Suggested revisions are invited and should be submitted to the director of the Exploration and Production Department, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005.

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Suggested revisions are invited and should be submitted to the Standards and Publications Department, API, 1220 L Street, NW, Washington, DC 20005, standards@api.org.

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Recommended Practice for Preproduction Qualification for Steel Plates for Offshore Structures

1 Introduction

1.1 PURPOSE

The purpose of these recommendations is to provide the purchaser with information which can be used to minimize the amount of time and testing necessary to prepare and certify fabrication welding procedures (and to assure that the steel to be supplied is inherently suitable for welding) with particular attention to fracture toughness and resistance to cracking of the heat affected zone. It is presupposed that welding procedures suitable for the demonstrated capabilities of the steel and intended service will be separately developed.

1.1.1 The specific testing required shall be that described in either Section 3 or 4 or both, as specified in the purchase order.

1.1.2 Demonstration of conformance to the recommendations of this practice qualifies a particular mill to produce steel manufactured to the specific chemical composition range, melting practice, and processing practice for which conformance was established. The qualification is applicable to all orders for material produced under the conditions qualified.

1.1.3 A significant change in chemical composition or processing practice that could be detrimental to either weldability or toughness shall require either a separate full qualification (for major change) or an abbreviated re-qualification (for minor change), as described in Section 5.

1.1.4 Prior qualification may be accepted for the fulfillment of the recommendations of this practice. Testing to a wider range of heat input, higher CTOD values, or lower test temperatures is encouraged, and shall be deemed to satisfy the minim recommendations of this Practice.

1.2 SCOPE

This Recommended Practice covers requirements for Preproduction qualification, by special welding and mechanical testing, of specific steelmaking and processing procedures for the manufacture of steel of a specified chemical composition range by a specific steel producer. This is a Recommended Practice for material selection and qualification, but not for the performance of production weld joints. This Recommended Practice was developed in conjunction with, and is intended primarily for use with, API Specifications 2W and 2Y. However, it may be sued as a supplement to other material specification s (e.g., API Specification 2H) if so desired.

1.3 GENERAL REQUIREMENTS

1.3.1 Unless otherwise specified, the testing recommended by this practice need only include material from a single heat of steel produced to the specific range of chemical composition to be qualified.

1.3.2 The plate processing, welding, and testing shall be conducted by or under the control of the steel producer, but shall be witnessed by a third party or a representative of a purchaser.

1.3.3 The test results, together with a detailed description of the processing of the steel, shall be documented by the producer and a copy provided to the purchaser. It is not intended, however, that proprietary information be included in the documentation. It is intended that the steel producer's "know-how" shall remain confidential. It is necessary, however, that sufficient information be included in the documentation package so that a purchaser can confirm at a later date that all essential procedures are being followed. At the very least, the manufacturer's process shall be designated by a code number or designation sufficient to provide traceability of process variables.

1.3.4 The chemical composition of the steel, as determined by heat analysis, shall conform to the requirements of the applicable industry standard under which it is to be produced. Within these typically broad limits, the steelmaker shall nominate the aim chemical composition and working range which define limiting essential variables for which the Preproduction qualification may be assumed to remain valid.

Tests conducted on any one heat shall qualify subsequent production heats described in Section 5.

1.3.5 Documentation shall include a complete characterization of the base metal properties of the steel tested, including the following:

a. Complete chemical composition, listing the elements in section 5.2 and all additions.
b. Tensile test results, including stress-strain curves to peak load.
c. Charpy V-notch transition curves for absorbed energy, lateral expansion opposite the notch, and fracture appearance. Each transition curve shall consist of a minimum of 12 specimens (at least 4 temperatures, sufficient to define the upper and lower shelf and 50% FATT). Samples for new qualifications to be mid-thickness with T-L orientation, at the following for locations:
   1. mother plate head, mid width
   2. mother plate head, plate edge
   3. mother plate tail, mid width
   4. mother plate tail, plate edge.

d. Drop-weight nil-ductility temperature.
e. Hardness traverse.
f. For new qualifications, results of centerline segregation control tests, to include macroetch of both slab and plate for concast, plate only for ingot cast steel.

1.3.6 Any reference to a steel having API RP 2Z qualification shall be accompanied by reference to the tested heat input range, CTOD test temperature, material strength or grade, and thickness.

2 References

2.1 The most recent editions of revisions of the following standards are referenced in this publication:

ASTM[1]

E 1290	*Standard Test Method for Crack Tip Opening Displacement (CTOD) Fractural Toughness Measurement*
STP-995	*Non-Linear Fracture Mechanics: Volume II Elastic Plastic Failure*

AWS[2]

A 4.3	*Determination of Diffusible Hydrogen*
D.1.1	*Structural Welding Code—Steel*

BS[3]

7448	*Part 1: Method for determination of K_{Ic}, critical CTOD, and critical J values of welds in metallic materials*
7448	*Part 2: Method for determination of K_{Ic}, critical CTOD, and critical J values of welds in metallic materials*
7363	*Methods for Controlled Thermal Severity (CTS) Test and Bead-on-Plate (BoP) Tests for Welds*

JIS[4]

Z 3158	*Method of Y-Groove Weld Cracking Test*

3 Qualification for HAZ Toughness

3.1 Each pre-qualification shall consist of preparation of three butt welds using test plates with either a K-bevel or single-bevel joint preparation (See Figure 1), subjection to agreement between purchaser and manufacturer. The weld shall be parallel to the final rolling direction and at mid width of mother plate. Test plates shall be of the maximum thickness intended for inclusion within the scope of the pre-qualification.

3.1.1 Pre-qualification test welds shall be made in the flat position using mechanized SAW process except that other mechanized welding process may be employed for the root pass and for the lowest heat input. The maximum angular distortion after welding and release of restraint shall not be greater than two degrees.

3.1.2 The welding consumables for pre-qualification welding shall be selected so that the CTOD fracture toughness of the weld metal in the final heat-treatment condition exceeds the required CTOD of the HAZ materials by at least 0.13 mm (0.005 in.) at –10°C (14°F), or at the temperature selected. To determine the CTOD value of weld metal, 100% of the fatigue crack should

[1]American Society for Testing Materials, 100 Barr Harbor Drive, West Conshokocken, Pennsylvania 19428-2959. www.astm.org
[2]American Welding Society, 550 NW LeJeune Road, Miami, Flordia 33135. www.aws.org
[3]British Standards Institution, 389 Chiswick High Road, London W4 4AL, UK. www.bsi-global.com
[4]Japanese Industrial Standards Committee, c/o Standards Department Ministry of International Trade and Industry, 1-3-1, Kasomigaseki, Chiyoda-K4, JAPAN. www.jisc.go.jp

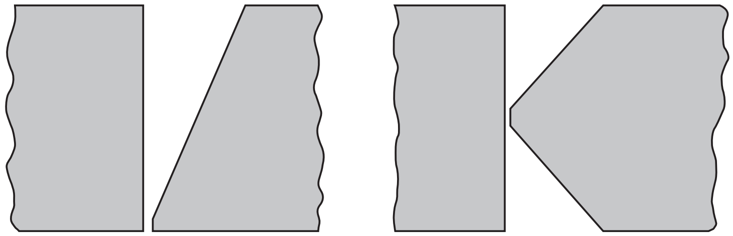


Figure 1—Single-bevel and K-bevel Weld Preparations

sample weld metal over the entire thickness and should be targeted to be within 1 – 2 mm (0.04 – 0.08 in.) of the fusion line over the central $^{2}/_{3}$ of specimen thickness. In addition, the hardness of the weld-metal deposit should be measured and should equal or exceed the hardness of the base material. These weld requirements are intended to ensure (1) that low weld metal toughness does not interfere with the interpretation of low CTOD results in the HAZ, and (2) that during HAZ testing, fatigue crack propagation into soft weld metal is not promoted. The weld metal toughness requirement contained in this section is not intended as a specification for production welding procedures.

3.1.3 The three butt welds shall be welded with pre-heat, heat input, and interpass temperature that span the pre-qualification range. The heat input (arc energy) range for pre-qualification shall encompass at least 0.8 to 4.5 kJ/mm (21 to 114 kJ/in.), unless the manufacturer elects a more restrictive heat input range for their particular steel supply (see 1.3.6). One weld shall be made at the lowest heat input to be pre-qualified with the lowest preheat/interpass temperature to be qualified in Section 4 [100°C (212°F) or lower] at the start of each weld pass adjacent to the tested HAZ. Preheat/interpass may increase 60°C (140°F) for weld passes further from HAZ. Another weld shall be made at the highest heat input to be pre-qualified with preheat/interpass temperature at 250°C (482°F) or higher at the start of each weld pass. The third weld shall be made with heat input at 3.0 kJ/mm (76 kJ/in.); the preheat temperature shall be 100°C (212°F), and the interpass temperature shall be allowed to build naturally, but not to exceed 250°C (482°F). Suitable equipment shall be employed for measuring these parameters quantitatively (temperature-indicating crayons are not acceptable). The heat input may be varied temporarily for initial or final passes if of practical necessity to complete a weld of the desired shape.

3.2 The HAZ of each test weld shall be evaluated by CTOD testing and by Charpy impact testing. Prior to evaluation, the test weld shall receive post-weld heat treatment if applicable. As-welded and post-weld heat-treated weldment conditions must be pre-qualified separately. Where PWHT is to be applied, the PWHT thermal cycle shall be recorded and reported.

3.3 CTOD TESTING

For the lowest heat input weld, a minimum of eight valid CTOD tests are required, and for the 3.0 kJ/mm (76 kJ/in.) weld and the highest heat input weld, five valid CTOD tests are required. All CTOD tests will be performed at –10°C (14°F), or at the lowest anticipated service temperature (LAST). All CTOD tests shall be in accordance with either British Standard BS 7448 Part 1 & 2 or ASTM E1290 (at Manufacturer's option), employing the preferred (Tx2T) test specimen (See Note 1) with a through-thickness notch and fatigue precrack extending halfway through the specimen width, nominally. The CTOD specimen length dimension shall be perpendicular to the weld and plate rolling direction (T-L orientation). The straight side of the weld should be straight enough so that a through-thickness notch can be placed normal to the plate surface and intersect the etched HAZ for at least 75% of the notch length over the central $^{2}/_{3}$ of the specimen thickness. More specimens than the number of required valid specimens may be necessary to allow for invalid results (per the CTOD test method) or failure to meet the notch placement criteria. The weld reinforcement may be removed, and the original plate surfaces cleaned to remove scale and superficial roughness, prior to the preparation of the specimens.

Note 1: The notch comprising machined notch and fatigue crack shall have a depth of 45% – 55% of the specimen thickness. TxT test specimens may be used for plate thickness T over 63 mm (2.5 in.).

Note 2: Test specimens in the as-welded condition may be mechanically stress relieved by lateral compression prior to fatigue precracking to promote crack front straightness. This procedure is described in "Fracture mechanics Tests on Welded Joints" by M.G. Dawes, et. al., in ASTM STP 995 *Non-Linear Fracture Mechanics: Volume II- Elastic Plastic Fracture* and BS 7448 Part 2: *Method for determination of K_{Ic}, critical CTOD, and critical J values of welds in metallic materials*.

Note 3: These CTOD testing requirements are summarized in Table 1.

Table 1—CTOD Testing Requirements

Requirement for Criteria	Welding Conditions (3.13) 0.8 kJ/mm (20kJ/in.) P/I*≤ 100ºC (212ºF)	3.0 kJ/mm (76 kJ/in.) 100ºC (212ºF) ≥ 250ºC (482ºF)	4.5 kJ/mm (114 kJ/in.) P/I* ≥ 250ºC (482ºF)
Number of CTOD Tests			
Minimum number of valid HAZ CTOD tests (3.3)	8	5	
Minimum number of valid HAZ CTOD tests with notch in the coarse-grained regions (3.3.2)	6	3	
Minimum number of valid HAZ CTOD tests with notch in the etched HAZ boundary material (3.3.2)	2	2	
Precrack Position: Metallurgical Requirements			
General HAZ straightness check regardless of precrack position (3.3.2)	Precrack able to intersect the etched HAZ for 75% of the central 2/3 of the specimen thickness	Same as for 0.8 kJ/mm (20kJ/in.)	
Precrack position requirement for coarse grain specimens	Choice of: 1. Same 15% rule as for 3 and 4.5 kJ/mm (76 and 114 kJ/in.), except that coarse grain region is within 0.3 mm (0.01 in.) of the fusion line (3.3.5), or 2. Best effort to locate precrack in coarse grain regions (3.3.6)	Three specimens show ≥ 15% of precrack in coarse grain regions within 0.5 mm (0.02 in.) of fusion line (3.3.7, 3.6). The 15% must be within central two thirds of specimen thickness (3.37)	
Precrack position requirement for etched HAZ boundary specimens	Choice of: 1. Same as for 3 and 4.5 kJ/mm (76 and 114 kJ/in.), except that the precrack must be within 0.3 mm (0.01 in.) of etched HAZ boundary (3.3.5) or, 2. Best effort to locate precrack in etched HAZ boundary material (3.3.6)	Two specimens with precrack in etched HAZ boundary material for ≥ 50% of the central 2/3 of specimen thickness (3.3.8)	
CTOD Acceptance Values (3.3.8)			
Grade 50, ≤ 3" (76 mm)	CTOD ≥ 0.25 mm (0.010 in.)	Same as for 0.8 kJ/mm (20kJ/in.)	
Grade 50, > 3" (76 mm)	CTOD ≥ 0.38 mm (0.015 in.)	Same as for 0.8 kJ/mm (20kJ/in.)	
Grade 60, ≤ 3" (76 mm)	CTOD ≥ 0.30 mm (0.012 in.)	Same as for 0.8 kJ/mm (20kJ/in.)	
Grade 60, > 3" (76 mm)	To be agreed	Same as for 0.8 kJ/mm (20kJ/in.)	
Stronger than Grade 60	To be agreed	Same as for 0.8 kJ/mm (20kJ/in.)	
Rejection Criteria and Retesting			
Rejection criteria for original valid CTOD results	Prequalification failed if more than one CTOD result is below acceptance value (3.3.1, 3.3.9)	Same as for 0.8 kJ/mm (20kJ/in.)	
Retesting	1. When using the quantitative precrack position strategy, the retesting requirements are the same as for the 3 and 4.5 kJ/mm (76 and 114 kJ/in.) welds (3.3.5). 2. When using "best effort" precrack positioning, 6 retests are required to replace a low result in etched HAZ boundary material and 10 retests are required to replace a low coarse-grain CTOD result. All retests must meet the acceptance value (3.3.6).	If one CTOD result is below acceptance value, five retest required. All retests must meet acceptance value (3.3.7, 3.3.8)	

*P/I = Preheat/Interpass Temperature

3.3.1 If more that one test fails to meet the required acceptance value, the steel fails the pre-qualification requirement. If only one of the initial valid CTOD tests fails to meet the required acceptance value, additional tests may be made duplicating the welding and precrack location conditions of the single specimen with the low CTOD value. All retests must meet the required number of retests as defined in section 3.3.8.

3.3.2 This section and the next four sections detail the examination methods and minimum criteria for demonstrating that the desired areas of the HAZ have been tested (see Note 4). These evaluations are performed on broken specimens after testing. However, pre-planning is necessary prior to notching of the test specimens if the criteria are to be satisfied. Each test specimen should be etched to reveal the HAZ position and structure before the notch is cut. The ability to place at least 75% of the notch in etched HAZ material over the central $^2/_3$ of the specimen thickness should be checked first; if this cannot be satisfied, a new test weld with a straighter HAZ may be necessary. If the HAZ straightness is satisfactory, the notch positions should then be scribed on the test specimens. For the lowest heat input weld, the notches of six specimens should be aimed to intersect the maximum amount of coarse-grain regions (which includes the unaltered coarse-grain HAZ and the inter-critically and sub-critically reheated coarse-grain HAZs (see Figures 3 and 4). For the 3.0 kJ/mm (76 kJ/in.) weld and the highest heat input weld, the notches of at least three specimens should be aimed to intersect the maximum amount of coarse-grain regions. For welds at all three heat inputs, the notches of a least two specimens should be aimed at the "etched HAZ boundary material" as defined in Figure 4d. After the notch positions have been scribed, notching, fatigue cracking, and testing of specimens should proceed in accordance with the CTOD test method selected in section 3.3.

Note 4: Specific regions of the HAZ are defined in section 3.6.

3.3.3 After the test specimens are broken, test results should be computed and their validity checked by the rules of the CTOD test method selected in 3.3; additional tests are necessary if some test results prove invalid. For each valid specimen, the position of the fatigue crack front shall be determined and documented in order to compare with the criteria in the following three paragraphs. A suggested sectioning procedure is shown in Figure 5a, however, other methods are also allowed. This cross section should be polished, etched, and photographed for documentation. Photographs should be taken at 3X to 6X and should have sufficient sharpness and contrast to distinguish local variations in HAZ microstructure.

3.3.4 For the lowest heat input weld, the fatigue crack front of six specimens shall be targeted to the coarse grain region within 0.3 mm (0.01 in.) of the fusion line on the base metal side over the entire thickness of the specimen (see Note 5). In addition, the fatigue crack front of at least two specimens shall be targeted at the etched HAZ boundary material (i.e., the SCHAZ). See section 3.6.1 and Figure 4d for the definition of etched HAZ boundary material. A post-test metallographic description of the plane of the examination (as defined in Figure 6) shall be provided for each specimen. For the lowest heat input weld, two strategies for precrack positioning criteria are available to the user. The first involves a quantitative assessment of the HAZ microstructure sampled by precrack. The second strategy involves a "best effort" for precrack positioning.The second strategy requires more retesting to replace a low result.

Note 5: The HAZ of the low heat input welds will be relatively narrow. It is the intent of this procedure to locate the fatigue crack front in the coarse grain regions although this material may be difficult to identify.

3.3.5 For the lowest heat input weld, the first option for precrack placement criteria is as follows:

At least three valid specimens must show the precrack was placed in the prescribed coarse grain HAZ material for at least 15% of the central $^2/_3$ of the specimen thickness, but the 15% need not be continuous. For this weld, the coarse grain regions are assumed to be within 0.3 mm (0.01 in.) of the fusion line. See section 3.6 for guidance on metallographic criteria and a description of the coarse grain regions to be included in the 15%.

At least two valid specimens must show the precrack was placed in etched HAZ boundary material for at least 50% of the central $^2/_3$ of the specimen thickness. See section 3.6 and Figure 4d for the definition of etched HAZ boundary material.

If only one of all initial valid tests (all precrack positions combined) fails the CTOD acceptance value, then five retests shall be conducted. All retests shall duplicate the precrack location of the failed CTOD specimen. All retests must meet the required CTOD value.

3.3.6 For the lowest heat input weld, the second option for precrack placement criteria consists of a best effort to achieve the desired microstructural sampling. Metallographic sectioning shall be conducted for information purposes only. If only one of all initial valid tests (all precrack positions combined) fails the CTOD acceptance value, and if this result is a coarse grain specimen, then 10 retests shall be conducted. If the single low test is an etched HAZ boundary material specimen, then six retests are required. All retests shall duplicate the precrack location of the failed CTOD specimen. All retests must meet the required CTOD value.

3.3.7 For the 3.0 kJ/mm (76 kJ/in.) weld and the highest heat input weld, at least three valid specimens must show the fatigue crack was placed in the prescribed coarse grain HAZ material for at least 15% of the central 2/3 of the specimen thickness, but the 15% need not be continuous. (See section 3.6 for guidance on metallographic criteria and a description of the coarse grain regions to be included in the 15%.) Notch placement in specimens selected to sample the CGHAZ regions should be aimed to intersect the maximum amount of CGHAZ adjacent to the fusion line. To satisfy the microstructural sampling requirements for the intermediate and high heat input weld sets, the notch should be targeted to be within 0.5 mm (0.02 in.) of the fusion line on the base metal side. For each specimen, at least 75% of the fatigue crack shall intersect the fusion line or etched HAZ over the central 2/3 of the specimen thickness. If necessary, the other half of the broken CTOD specimen may be sectioned as well to aid this determination. If less that three specimens meet the crack placement criteria, additional specimens shall be prepared and tested. If only one of all initial valid tests (all precrack positions combined) fails the CTOD acceptance value, then five retests shall be conducted. All retests shall duplicate the precrack location of the failed CTOD specimen. All retests must meet the required CTOD value.

3.3.8 For the 3.0 kJ/mm (76 kJ/in.) weld and the highest heat input weld, at least two valid specimens must show the fatigue crack was placed in the etched HAZ boundary material (i.e., the SCHAZ) for at least 50% of the central 2/3 of the specimen thickness. (See section 3.6.1 and Figure 4d for definition of etched HAZ boundary material.) If less than two specimens meet this crack placement criterion, additional specimens shall be prepared and tested. If only one of all initial valid tests (all precrack positions combined) fails the CTOD acceptance value, then five retests shall be conducted. All retests shall duplicate the precrack location of the failed CTOD specimen. All retests must meet the required CTOD value.

3.3.9 For each test weld, every CTOD test result found valid by the criteria of the CTOD test method selected in section 3.3 shall be included in the final evaluation. (The preceding paragraphs require that, depending on heat input, there be at least 5 or 8 such results and that some of the specimens satisfy additional requirements regarding fatigue-crack position.)

The following criteria are for steels with a specified minimum yield strength of 60 ksi (420 MPa) or less. No more than one of the original valid results, and none of the retests, shall exhibit a CTOD less than the following:

	Grade 50 SMYS of 50 ksi (350 MPa)	Grade 60 SMYS of 60 ksi (420 MPa)
Thickness thru 76 mm (3 in.)	0.25 mm (0.010 in.)	0.30 mm (0.012 in.)
Thickness over 76 mm (3 in.)	0.38 mm (0.015 in.)	Criteria as agreed

The CTOD criteria for steels with a specified minimum yield strength greater than 60 ksi (420 MPa), are to be agreed upon between the manufacturer and the purchaser.

3.3.10 Retesting, other than to replace invalid specimens, to meet fatigue-crack position requirements, or to make additional tests as provided in sections 3.3.5 through 3.3.8, is not generally permitted. Pre-qualification based on retesting shall be subject to acceptance by the purchaser, and the documentation in such cases shall include all data and photographs from the unsuccessful attempt(s) as well as the metallurgical justification for retesting.

3.4 Complete Charpy V-notch test transition curves employing at least eight specimens each shall be determined for the coarse grain and the unaltered sub-critical HAZ locations at both the root and the quarter-thickness locations (a total of four transition curves). For each case, the V-notch shall be placed so that the notch root line is in the through-thickness direction and the direction of crack propagation is along the weld length (T-L orientation).

3.5 All pre-qualification tests results are to be reported whether valid or invalid. If invalid, the reason for invalidity shall be stated.

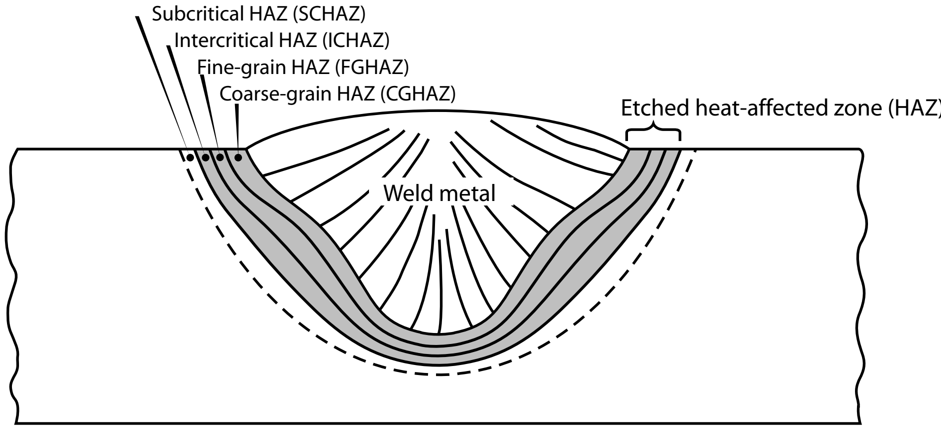


Figure 2—Various Regions of a Single-pass, Bead-on-plate Weld

3.6 COMMENTARY

Four HAZ regions are defined in the bead-on-plate weld cross section shown in Figure 2. If a second pass is placed as shown in Figure 3a, then some of the first-pass HAZ regions are eliminated, while others are significantly altered. Figure 3b shows Figure 3a with some of the altered and unaltered regions identified.

3.6.1 In a multi-pass weld with one plate edge unbeveled, the overlapping HAZs that penetrate the unbeveled edge appear as shown in Figure 4a. Columnar weld metal is also identified in this figure and includes weld metal that has not been affected by the heat of subsequent passes and weld metal that has been sub-critically reheated (i.e., a SCHAZ in weld metal). Because this weld metal is relatively unaffected, it still displays a columnar structure when etched. Weld metal that has been inter-critically or super-critically reheated (i.e., above the A1 or A3 temperatures, respectively) does not display a perfectly columnar structure when etched. The weld metal HAZs are shown in Figure 4 and the portions that have been heated above the A1 are shaded and contain broken columnar lines. Redrawing Figure 4a so that only unaltered CGHAZ areas are depicted results in Figure 4b. Redrawing Figure 4b to include the IRCG and the SRCG results in Figure 4c. Notice that the unaltered CGHAZ and SRCG are directly adjacent to the fusion line where the unrefined columnar weld metal contacts the base metal. The approximate position of the CG regions of interest for fatigue crack sampling can be determined using the following procedure: (1) draw arcs along the fusion line only directly adjacent to the regions of unrefined columnar weld meta, (2) draw a second set of arcs parallel to the first set, but 0.5 mm (0.02 in.) away on the base metal side (0.3 mm (0.012 in.) for the lowest heat input weld). The regions between the two sets of arcs contain the unaltered CGHAZ and the SRCG. The IRCG lies directly adjacent to the SRCG (see Figure 4c) .

Figure 4d highlights the "etched HAZ boundary material". Notice that the etched HAZ boundary is the outer line of the visible etches HAZ and lies between ICHAZ and SCHAZ. The etched HAZ boundary material is defined as follows: draw a line along the visible etched HAZ boundary; draw another line parallel to the first, but 0.5 mm (0.02 in.) away on the base metal side (0.3 mm [0.012 in.] for the lowest heat input weld). The region between the two lines is the etched HAZ boundary material. Notice that the etched HAZ contains the ICHAZ.

3.6.2 The fatigue crack in the "CGHAZ" CTOD specimen should be placed where it will sample the maximum amount of the unaltered CGHAZ, the IRCG and the SRCG (Figure 4c). When conducting an "etched HAZ boundary material" CTOD test, the fatigue crack should be placed where it will sample the maximum amount of the unaltered SCHAZ (Figure 4d). To properly define the unaltered CGHAZ microstructure for any weld, the HAZ microstructure adjacent to the square-edge fusion line of each test specimen should be visually inspected using an optical microscope at magnifications of 5X and 10X. This inspection should be completed in sections 3.6.4 and 3.6.5. The relative grain size and the width of unaltered CGHAZ regions should be established for each specimen. Unaltered CGHAZ regions should be identified as the regions having the largest observable grain sizes which are located along the fusion line adjacent to unrefined columnar weld metal. The visual inspection that defines the unaltered CGHAZ regions intended to be sampled for those specimens to be notched in the CGHAZ. This inspection is important as the width of the

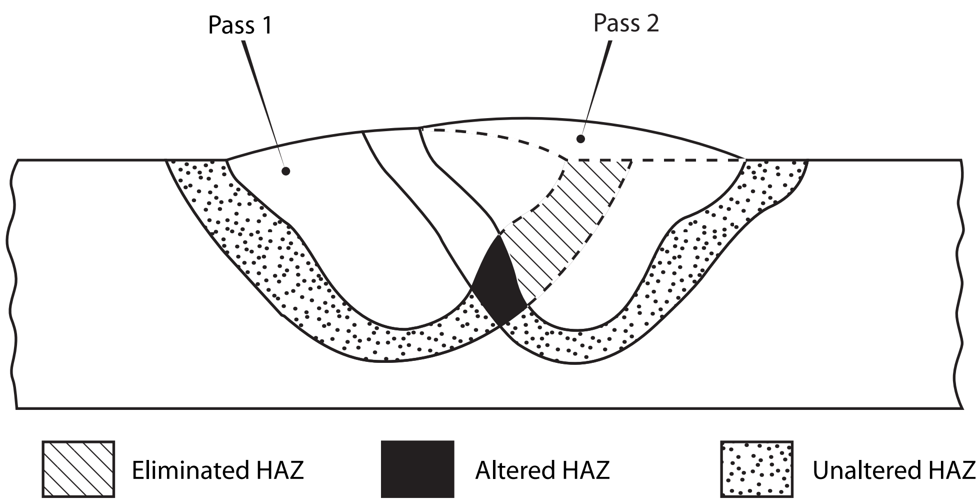
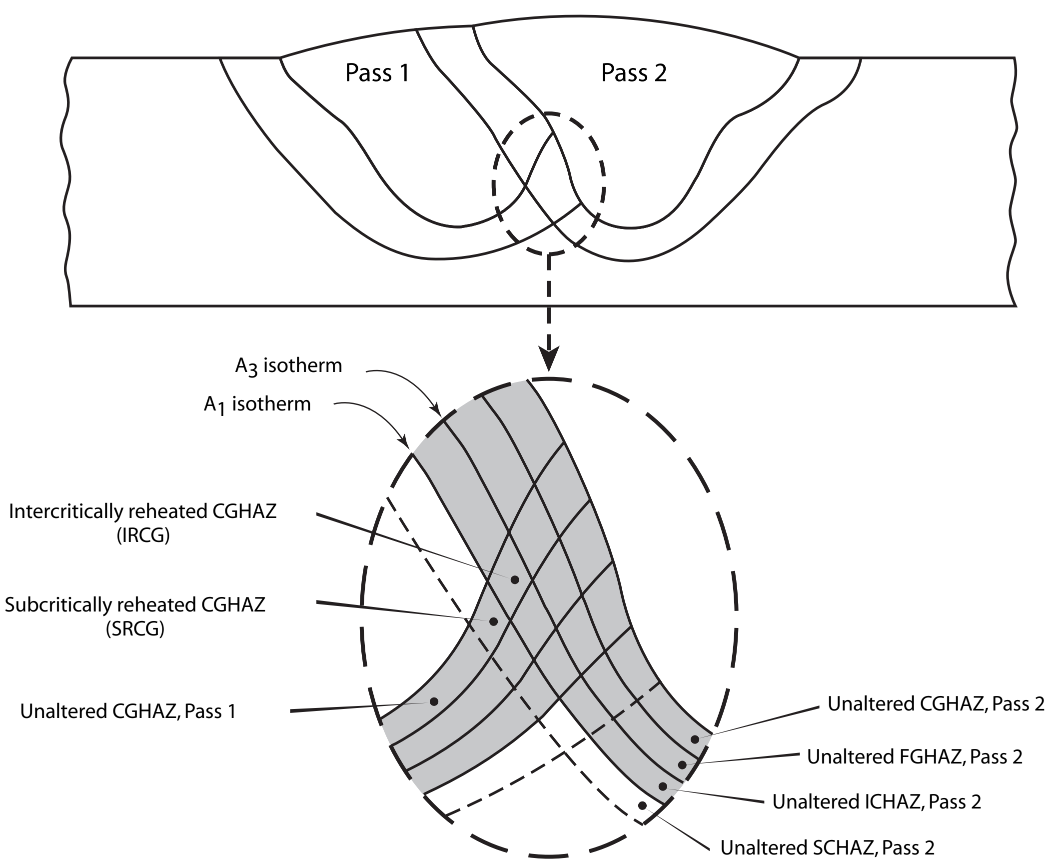


Figure 3a—Elliminated, Alterd and Unaltered Regions of a Two-phase, Bead-on-plate Weld



Note: The shaded region indicates the etched HAZ.

Figure 3b—Identification of Some Altered and Unaltered Regions

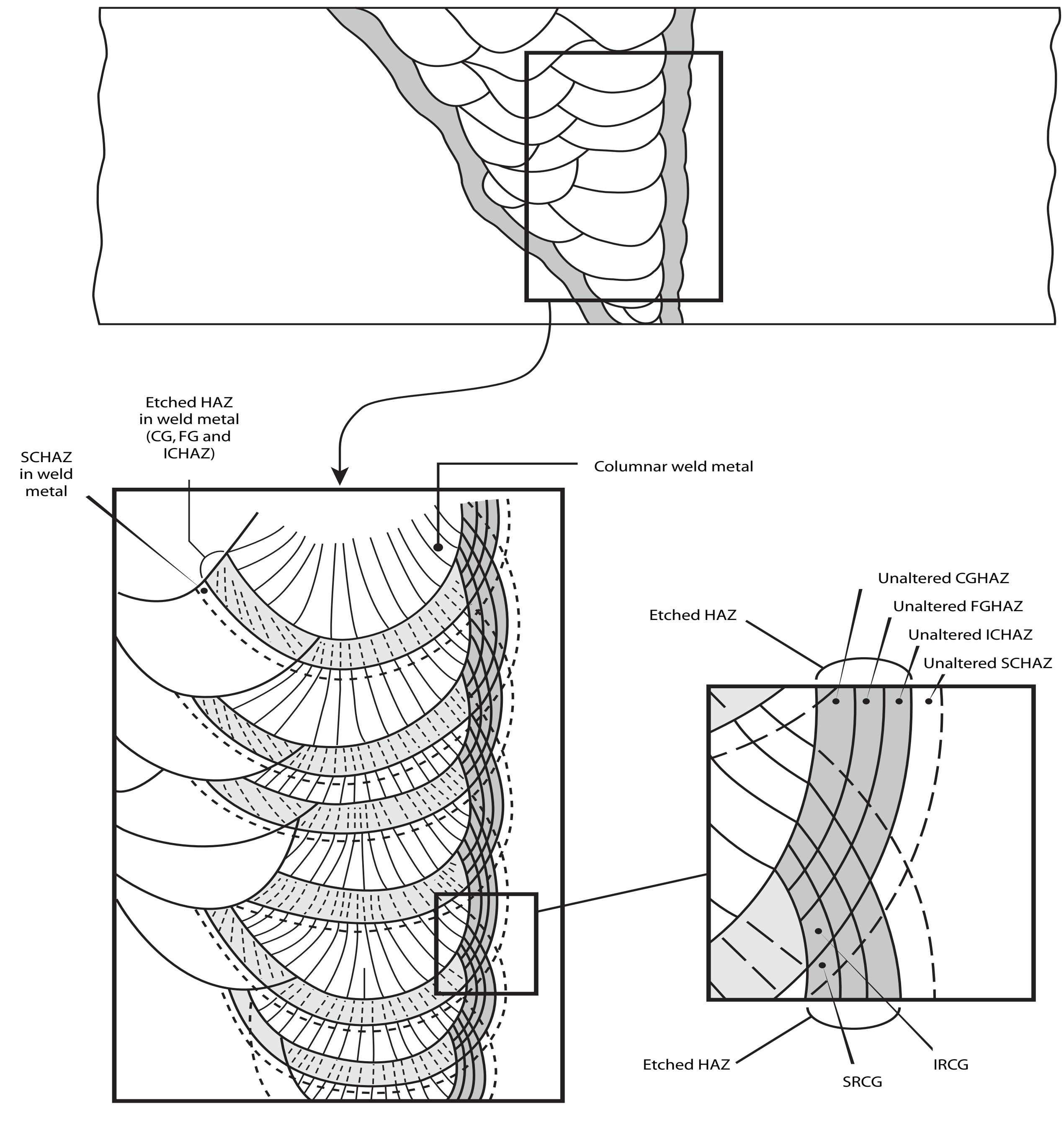
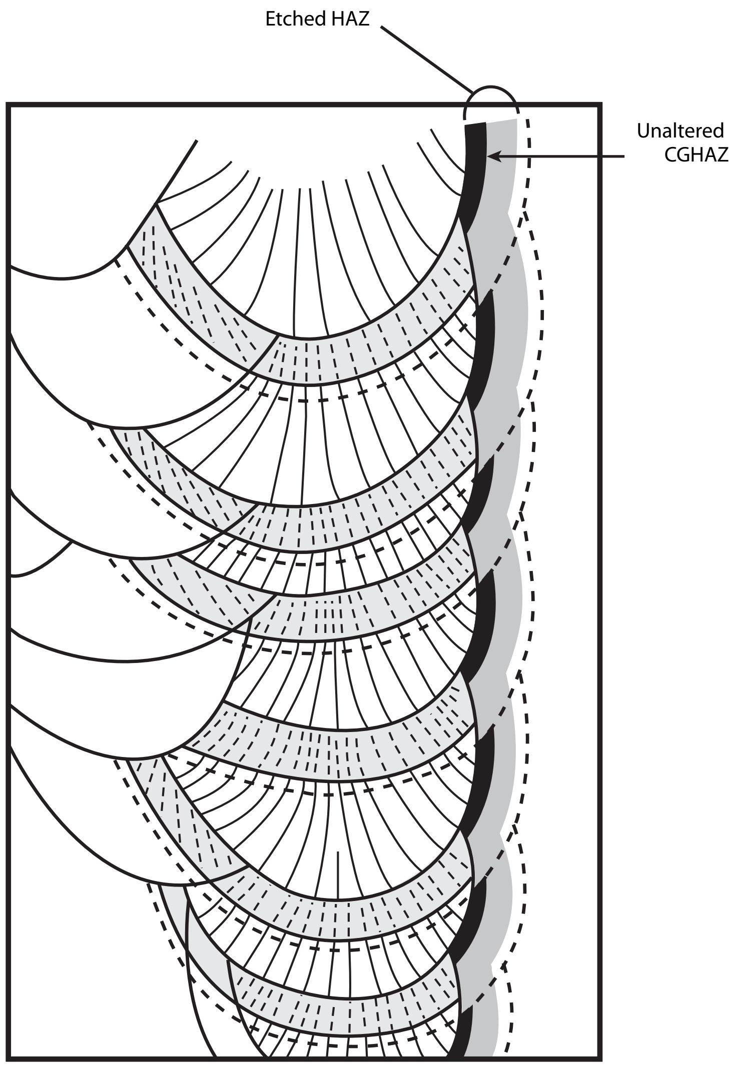
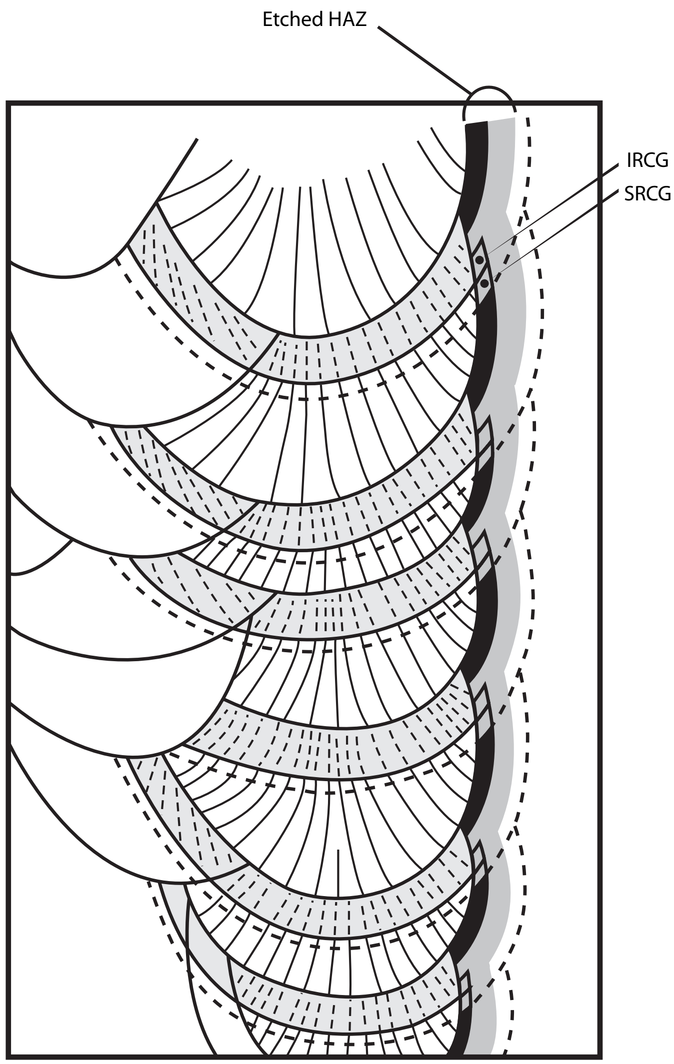


Figure 4a—HAZ Regions in a Multi-pass Weld with One Plate Edge, Unbeveled



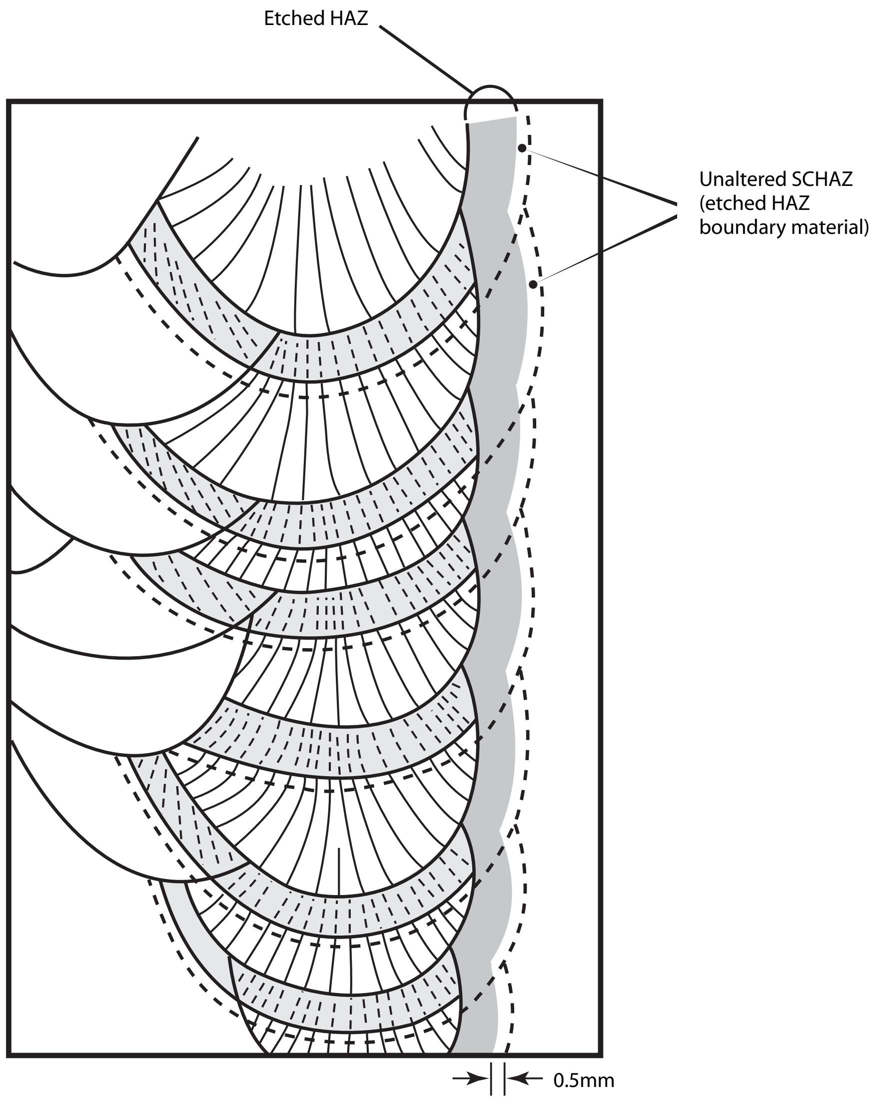
Note: Figure 4b is taken from Figure 4a except that some of the individual HAZ boundries have been removed and the unaltered CGHAZ is highlighted in black.

Figure 4b—Unaltered Coarse-grain HAZ (CGHAZ) in a Multi-pass Weld with One Plate Edge, Unbeveled



Note: Figure 4c is a modification of Figure 4b. In the figure above, the IRCG and SRCG regions are highlighted using "rectangles" to show their position. Later, in Figures 5b and 6, the IRCG and SRCG will be blackened so that all CG of interes for fatigue crack sampling are are highlighted black.

Figure 4c—Intercritically and Subcritically Reheated CGHAZ Regions (IRCG and SRCG, Respectively)



Note: Figure 4d is a modification of Figure 4b. In Figure 4d, the CGHAZ regions are not highlighted, but the unaltered SCHAZ is denoted. Theoretically, the unaltered SCHAZ includes all material heated to temperatures less than the A_1. For the purposes of this document, the unaltered SCHAZ will be limited to a width of 0.5 mm just outside of the etched HAZ and this region will be called "etched HAZ boundry material."

Figure 4d—Unaltered Subcritical HAZ (SCHAZ)

CGHAZ regions can vary as a function of heat input, bead placement along the fusion line and steel chemistry. Additionally, it is important that each test specimen undergo inspection as the volume and position of the CGHAZ regions can vary through any given weldment

3.6.3 After the CTOD specimens are tested and separated into two pieces, they must be sectioned as shown in Figure 5a (or similar) to determine the actual fatigue-crack location with respect to the various HAZ regions. The saw cut in the fracture surface should be placed so that the resulting cross section reveals the area sampled by the front portion of the fatigue crack. Because the fatigue crack may tunnel slightly (propagate further in the central portion of the specimen), the saw cut may actually cross the fatigue crack/fracture face boundary. This cross-over will usually occur close to the specimen edges, as shown in Figure 5a. In the case of a CGHAZ CTOD, the percent coarse grained region sampled by the fatigue-crack is calculated as follows with reference to Figure 5b. First, an arc is drawn along the fusion line adjacent to the unrefined columnar weld metal and the IRCG. Next, and arc parallel to the first arc is drawn 0.5 mm (0.02 in.) away in the HAZ (0.3 mm [0.012 in.]) for the lowest heat input weld). The CG regions (unaltered CGHAZ, IRCG and SRCG) are the regions between the arcs. The percent coarse grained region sampled by the fatigue-crack is calculated as shown in Figure 5b.

3.6.4 Although the sectioning analysis can be conducted by removing a sample from the only "weld half" of the CTOD specimen, as shown in Figure 5a, it is suggest that both halves of the CTOD specimen be sections, as shown in Figure 6. Sectioning both halves provide a better visual representation of the areas sampled by the fatigue-crack.

3.6.5 A method analogous to the technique shown in Figure 5a and Figure 6 can be used to determine the percentage of the "etched HAZ boundary material" sampled from the etched CTOD specimens. To document the sectioning results, high-quality photographs should be taken of the sectioned specimens at 3X to 6X magnification.

3.6.6 As the intent of this specification is to aid in ensuring that the HAZ toughness properties of the candidate steel are adequate, it is necessary that sufficient unaltered CGHAZ microstructure exists in the test specimens so that potentially "worse case" conditions are effectively evaluated. To aid in producing sufficient quantities of unaltered CGHAZ, bead placement techniques should be employed in CGHAZ notched specimens such that HAZ refinement is limited. Weld procedures should be designed to produce unrefined columnar weld microstructure along the square edge fusion line (see Figure 4b). Ideally, a total of 15% to 25% of the weld metal along the straight fusion line in the central $^2/_3$ of the specimen thickness should be unrefined columnar weld metal. The optimum beat placement and sequence will be dependent on the thickness of the material consumable size and the heat input. It is recommended that a trial weld be produced to confirm that the intended pre-qualification weld procedure can produce appropriately straight fusion line while generating desirable amounts of unrefined columnar weld metal adjacent to the fusion line.

4 Delayed Cracking Test

4.1 PURPOSE

These tests are intended to demonstrate normal welding behavior of the material and to provide guidance in the selection of preheats. The tests shall be performed as part of the pre-production qualification of a steel as documented in section 1.3. Two types of tests shall be conducted, representing different levels of restraint.

4.2 CONTROLLED THERMAL SEVERITY (CTS) TEST

The CTS test represents moderate restraint. See British Standard BS 7363 *Methods for Controlled Thermal Severity* (*CTS) Test and Bead-on-Plate (BoP) Tests for Welds*. The heat input shall be 1 kJ/mm (25 kJ/in.) max.

4.3 THE Y-GROOVE TEST

See Japanese Industrial Standards (JIS) Z 3158 *Method of Y-Groove Weld Cracking Test*. The Y-Groove Test represents high restraint. The heat input shall be 1.7 kJ/mm (43 kJ/in.) max.

4.4 REQUIREMENTS

4.4.1 The specimens shall be welded with electrodes having a yield strength level at least matching the base plate. A nominal hydrogen level of 3-5 ml/100g of weld deposit is desired, as typically produced by a properly dried low hydrogen electrode. Hydrogen may be determined by IIW method (over mercury), by AWS A 4.3 *Determination of Diffusible Hydrogen*, or by a gas chromatographic method.

4.4.2 The maximum thickness of the test plates shall be the actual thickness or may be limited to 2 in. (50 mm) with either test, as this thickness represents and approximate maximum level of restraint intensity. Thicker plates may be evaluated by machining the excess thickness equally from both surfaces.

4.4.3 The results of both tests shall be presented in terms of the level of preheat necessary to prevent delayed cracking of the base metal at the maximum thickness tested. Cracking in the weld deposit shall require retesting.

4.4.4 In order to be acceptable, all CTS tests shall exhibit no cracking at 80°C (176°F) and all Y-Groove tests shall show no cracking at 130°C (266°F) or at lower temperatures established by the manufacturer for either test.

4.5 COMMENTARY

Interpretation of the results in terms of fabrication welding procedures may consider Annex XI, "Guidelines on Alternative Methods for Determining Preheat," in the AWS D.1.1 *Structural Welding Code—Steel*. The AWS Guidelines are consistent with the preheats cited herein at low heat inputs; they also provide for lower preheats when high heat input welding is used.

5 Re-Qualification

5.1 Once a particular steel specification, facility, chemistry, and processing have been qualified to API RP 2Z, there is no set time limit on the validity of that qualification. Over time, however, changes in important steelmaking variables may occur. When MAJOR changes have occurred, full re-qualification shall be conducted. When only MINOR changes occur, a "fast track" abbreviated re-qualification may suffice, as agreed. This section provides guidance on the definition of major and minor changes, and on the scope of testing required for fast-track re-qualification.

5.2 Unless otherwise restricted by the applicable steel specification, a MAJOR change in ladle chemistry is defined by the following limits (weight percent tolerance):

carbon	+0.02, –0.03%
manganese	± 0.20%
phosphorus	+0.010%, –no limit
sulfur	±0.005%
silicon	+0.15%, –no limit, but 0.15% min
copper	±0.15%
nickel*	+0.50%, –0.15%
chromium	±0.10%
molydenum	+0.04%, –0.06%
niobium	±0.010%
titanium	±0.010%
aluminum	±0.025%
vanadium	±0.02%
boron	±0.0010% (±10 ppm)
nitrogen	
total	+0.0025, 0.0045% (+25 ppm, –45ppm)
free	+0.0025%,–no limit $N_{free} = N_{total} - 0.29$ Ti
CE**	+0.02, –0.03
Pcm	+0.02, –0.03

*For plates with a lesser thickness than the pre-qualified plates, the reference (prequalified) nickel content may be reduced by 0.10% for each 25.4 mm (1.0 in.) reduction in thickness or proportionate part thereof.

**Further reduction in the minimum CE tolerance are permissible for thinner plates upon agreement with the purchaser.

5.3 Tolerances for minor and major changes in melting, casting, and processing variables other than chemistry are given in Table 2.

5.4 Increases in the qualified range of thickness or heat input require repeating the full qualification as described in Section 3, for those parameters extending the original range. For example, if the original qualified heat input range was 0.8 kJ/mm to 4.5 kJ/mm (20 kJ/in. to 114 kJ/in.), then full qualification testing is only necessary at the 6 kJ/mm (152 kJ/in.) heat inputs, and not the previously qualified lower heat inputs.

5.5 If changes to the steel processing variables exceed only the tolerances defined as minor, then the following "fast track" protocol may be considered. New tests are to be conducted in the same manner and to the same extent as the baseline tests described in sections 1.3.5 and 3.4.

For all four plate locations defined in section 1.3.5.c, base metal Charpy V-Notch transition curves (min. 12 specimens each) shall demonstrate 50% shear transition at or below the temperature shown in available tests from the original qualification.

Table 2—Tolerances for Minor and Major Changes in Melting, Casting, and Processing Variables Other Than Chemistry

Essential Variables	Minor Change	Major Change
Steelmaking electric/BOF/etc.		site or method
Ladle refining or argon-oxygen decarburization		site or method
Casting: ingot vs. strand (continuous)		facility or method
Slab reheat LMP (temp & time, 900°C threshold)		±2.5%
Processing: normalize/Q&T/TMCP/ control roll		method
TMCP accelerated cooling or quench		method
Total reduction ratio		+unlimited, –15%
Reduction at TMCP or control roll finish mill		+unlimited, –15%
TMCP or control roll start temp	±25°C (±45°F)	
TMCP or control roll stop temp	± 25°C (±4 5°F)	
Cross-rolling ration, steels w/o inclusion shape control	+unlimited, –25%	
Normalizing LMP (900°C threshold)	±2%	
Austenitizing LMP for Q&T (900°C threshold)	±2%	
TMCP AC or quench start temp	±35°C (63°F)	
TMCP AC or quench stop temp	±50°C (90°F)	
TMCP AC or quench cooling rate or duration	±20%	
Temper or ageing LMP (300°C threshold)	+4%, –2%	

Note:

1. Tolerances for major and minor change are relative to the actual or singular target value for the previously qualified plate at each given thickness. Other changes that might adversely affect HAZ toughness should be agreed between steelmaker and purchaser.
2. Larson-Miller Parameter
LMP = max T (°K) *[20 + log time (hours above threshold)]
3. Processing variables may vary according to a schedule based on slab & plate thickness and dimensions, as determined by the manufacturer, to ensure that the final product meets its specification, and as bracketed by the original full CTOD pre-qualification. Variations from the prior schedule larger than MINOR tolerances in Table X trigger fast-track re-qualification for RP 2Z purposes.

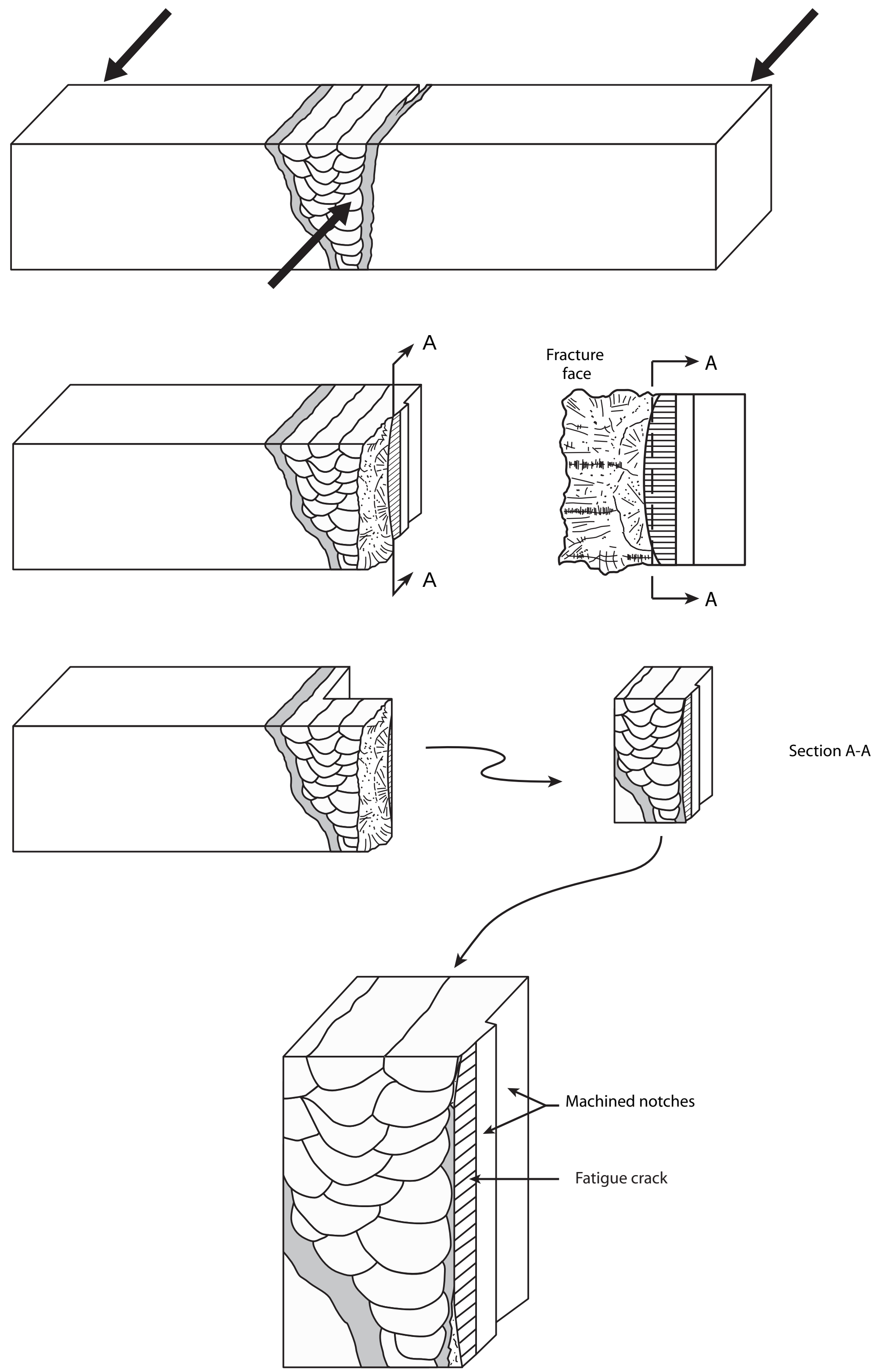
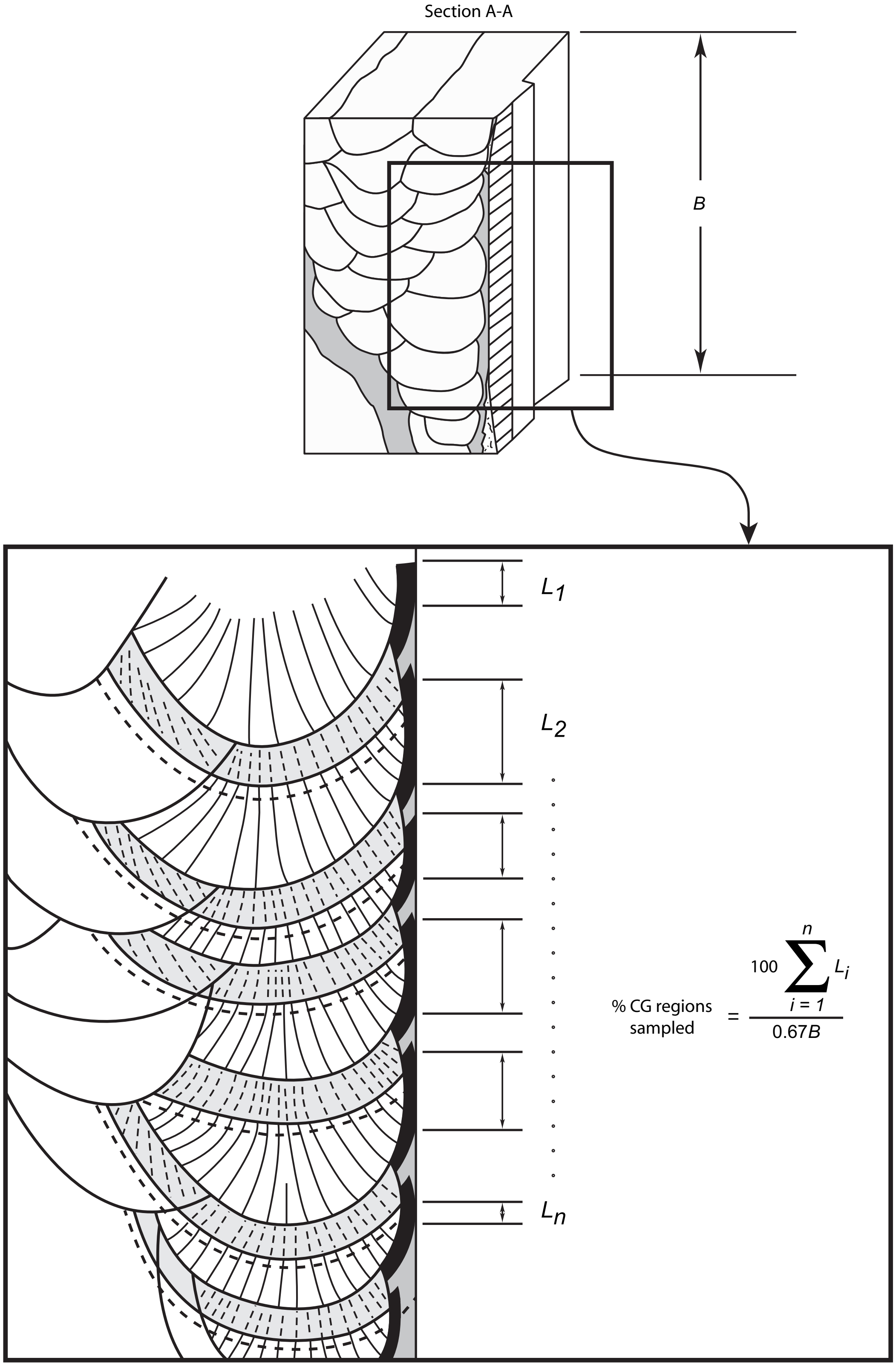


Figure 5a—Sectioning the Weld Half of a HAZ CTOD Specimen



Note: This view of the HAZ is similar to Figure 4c, except that the IRCG and SRCG have been highlighted black. In the above figure, all CG regions of interest for fatigue crack sampling are highlighted black.

Figure 5b—Calculation of CG Region Sampled by the Fatigue Crack Tip

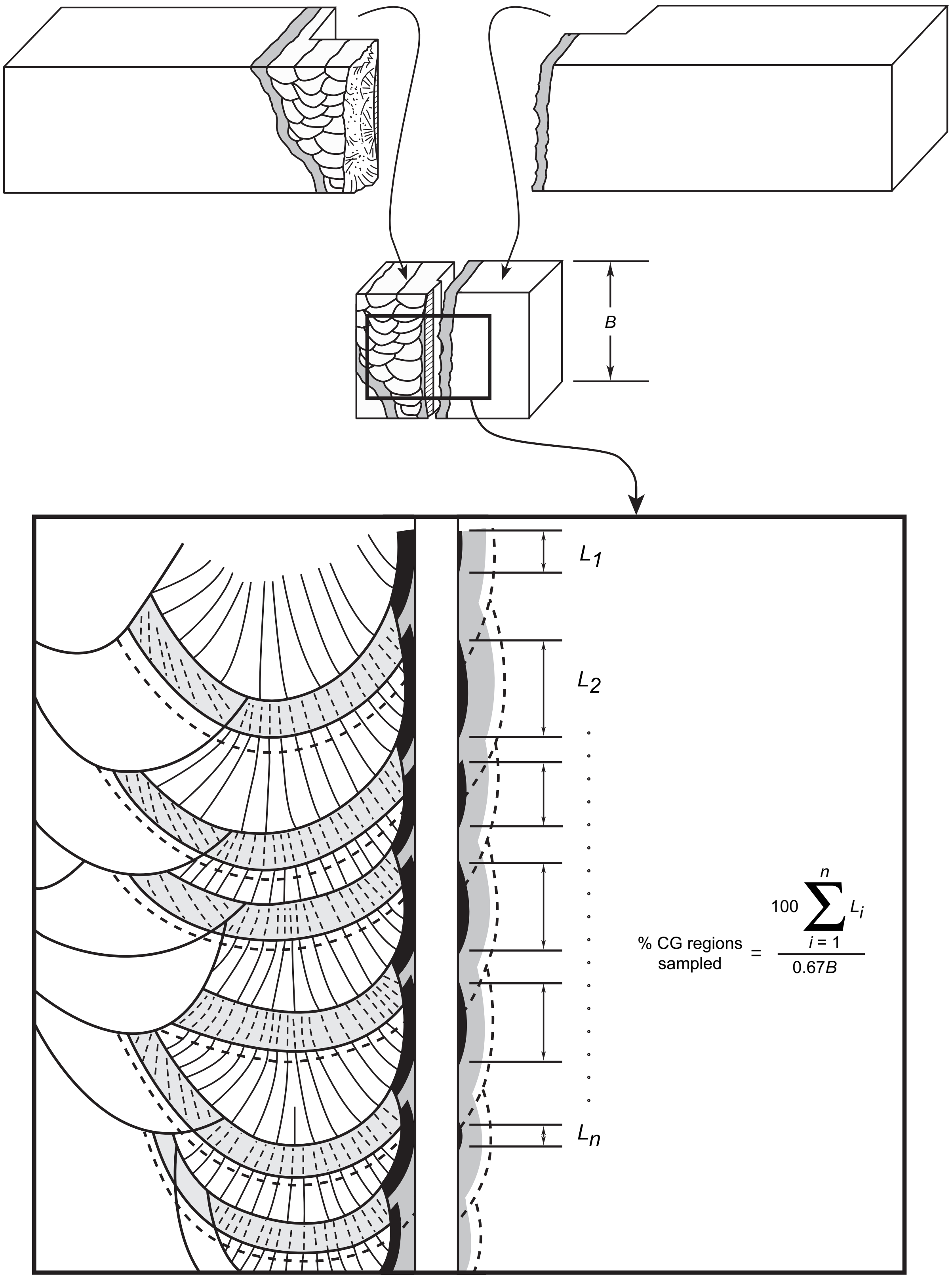


Figure 6—Sectioning Both Halves of a HAZ CTOD Specimen to Calculate CG Region Precentage

APPENDIX A—SUGGESTIONS FOR ORDERING API RP 2Z PRE-PRODUCTION QUALIFICATION

In placing orders for pre-production qualifications in accordance with API RP 2Z, the purchaser should specify the following on the purchase order:

Governing steel specification and grade, noting whether CTOD testing (Section 3) or delayed cracking test (Section 4) or both shall be performed.

Section 4: Optional LAST for HAZ Toughness

Attention is called that some other specific requirements may be subject to agreement between the purchaser and the manufacturer.

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